

# Time-domain astronomy with *Fermi* GBM in the Multi-Messenger Era

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on behalf of the *Fermi* GBM team

7<sup>th</sup> International *Fermi* Symposium

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# Fermi Gamma-ray Space Telescope

<http://gammaray.nsstc.nasa.gov/>

## GBM:

- FOV >8sr
- Whole sky every ~90min

## Data products:

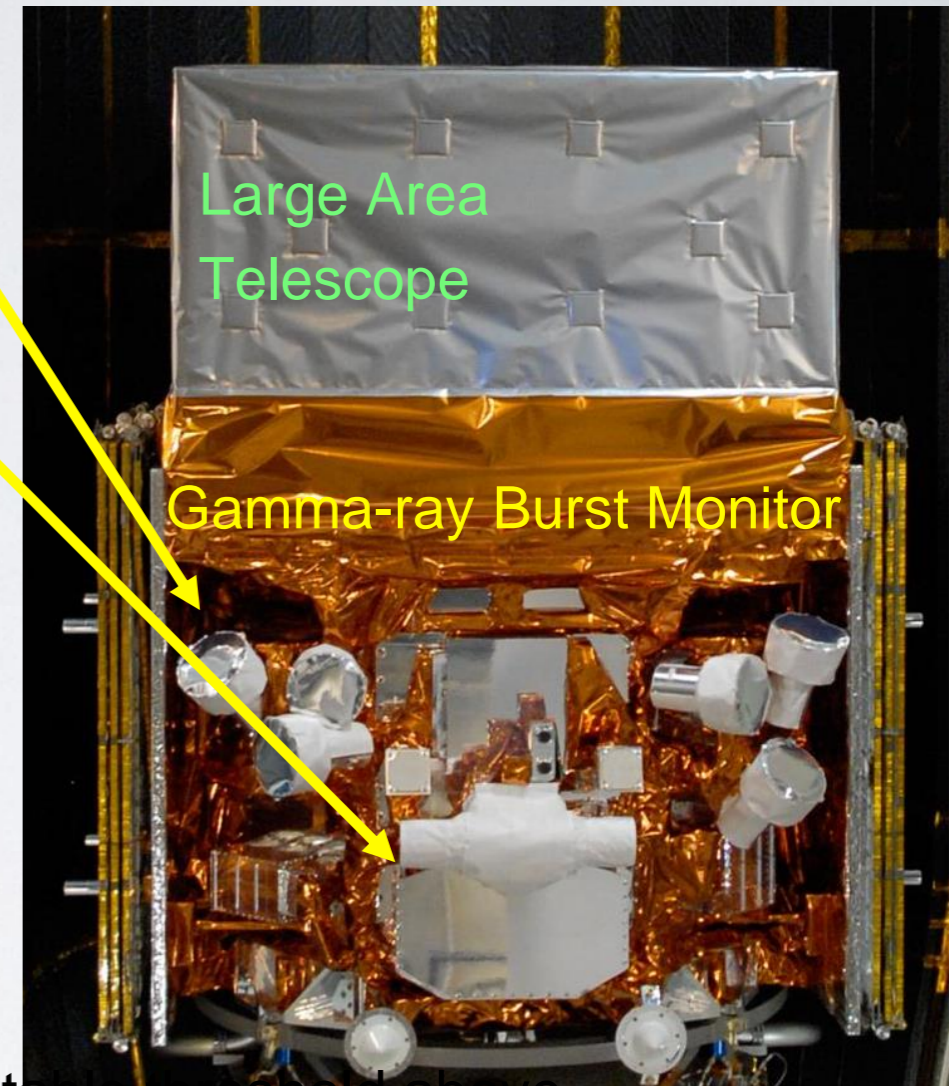
- CTIME (continuous high time resolution)  
— 256 / 64 ms, 8 energy channels
- CSPEC (continuous high spectral resolution)  
— 4096 / 1024 ms, 128 energy channels
- TTE / CTTE (time tagged events)  
— 2 $\mu$ s, 128 energy channels

## Triggering algorithms:

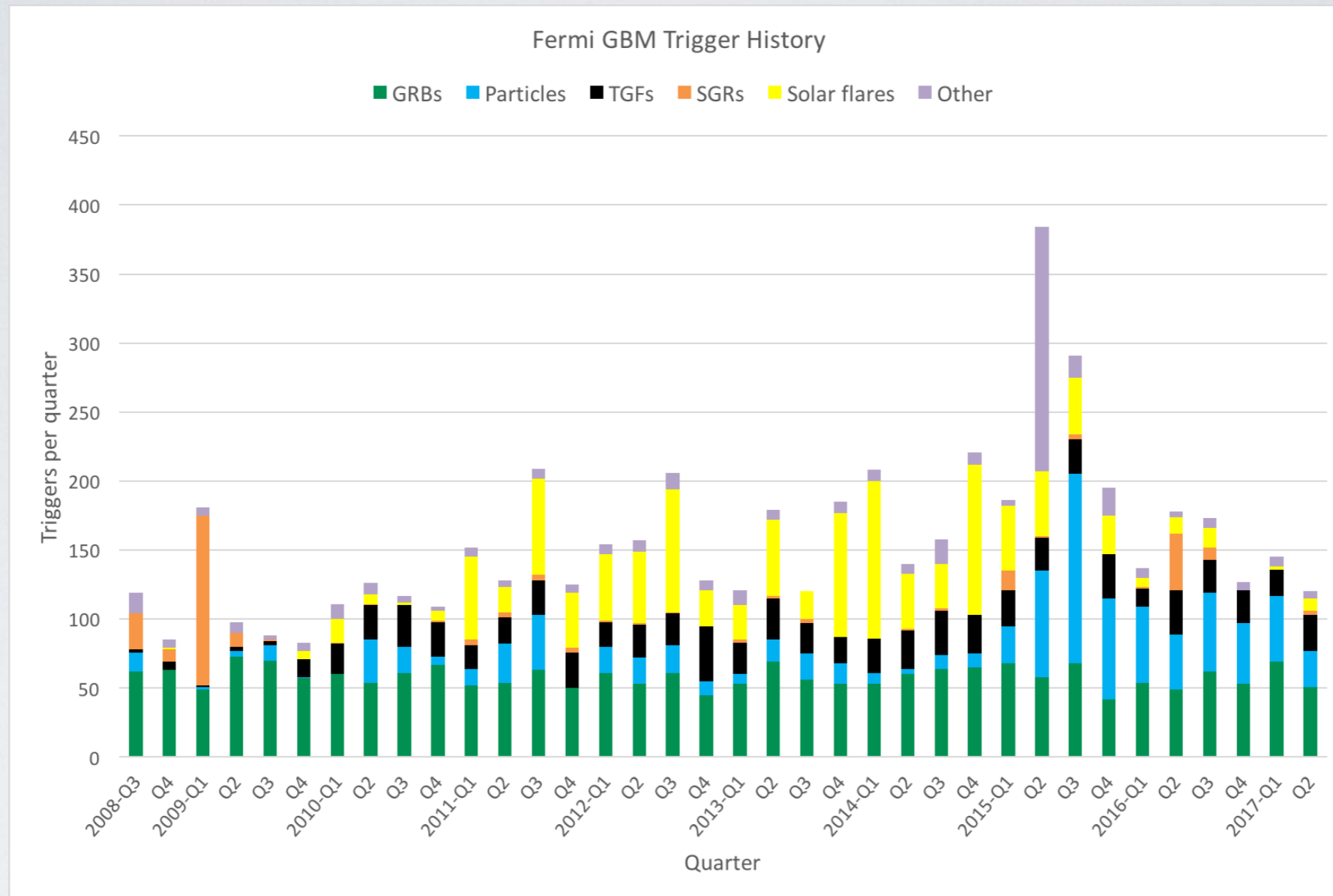
- In-orbit count rate increase in 2+ NaI detectors above adjustable threshold above background
  - 10 timescales — 16ms up to 4.096s
  - 4 energy ranges — [50-300], [25-50], >100, >300 keV
- Ground-based offline search for rate increase
- Earth occultation
- Pulsar phase folding

12 NaI detectors  
(8keV—1MeV)

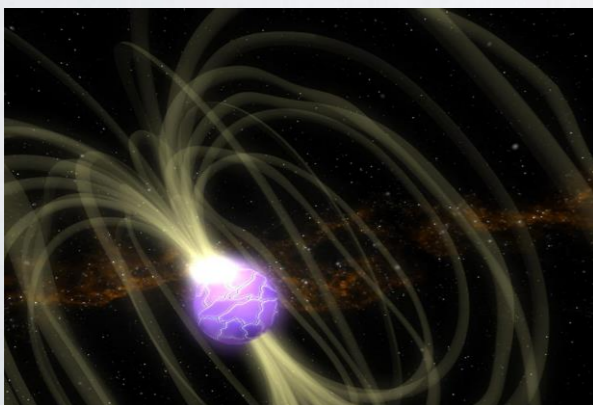
2 BGO detectors  
(200keV—40MeV)



# Fermi GBM Science



Galactic — pulsars, magnetars



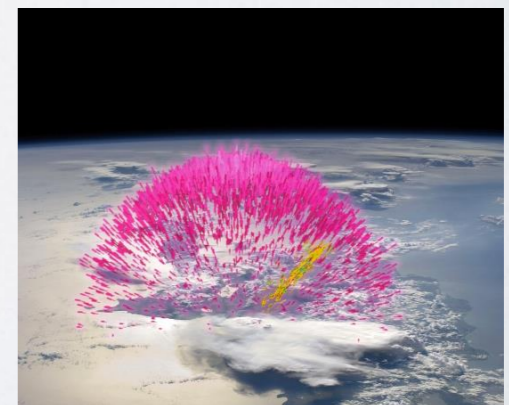
Colleen A. Wilson-HODGE

Gamma-Ray Bursts



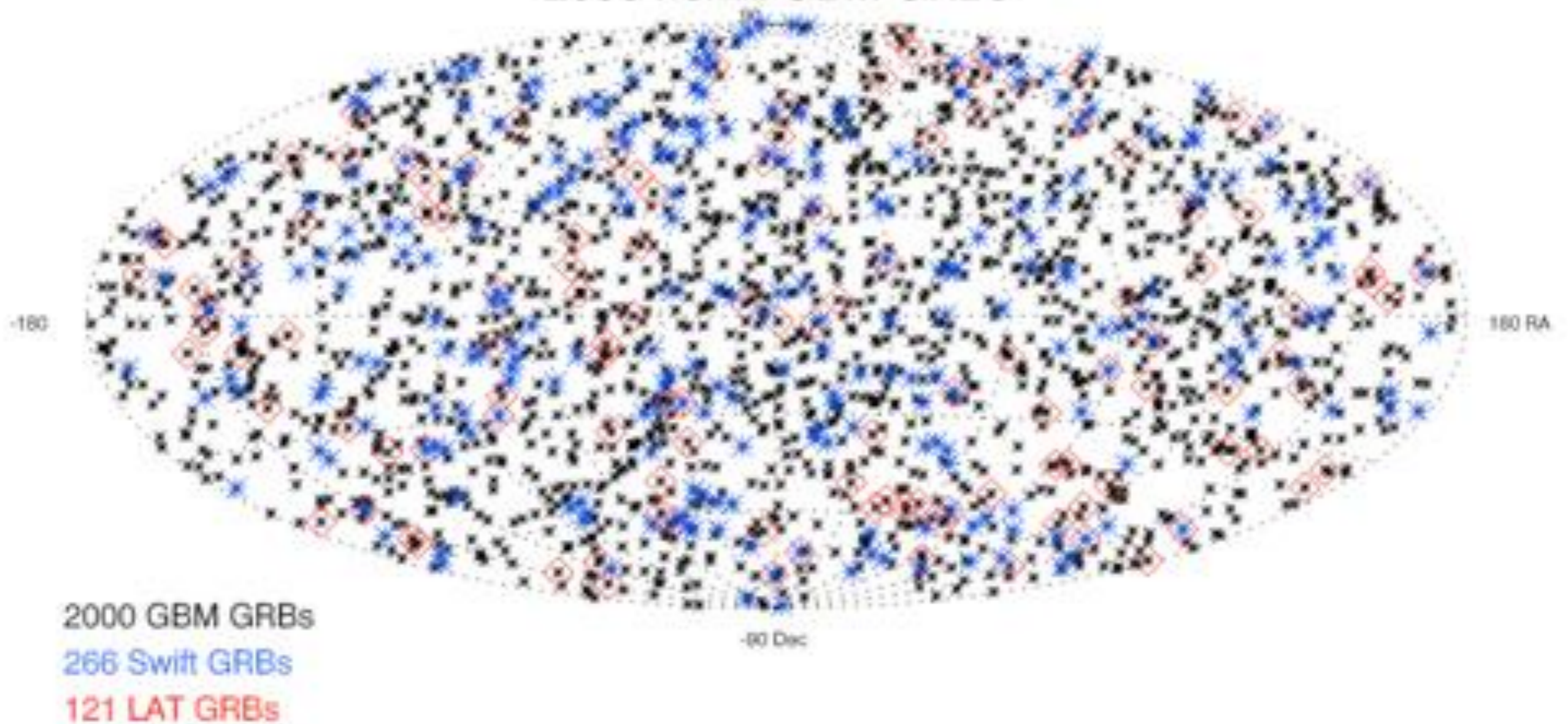
7<sup>th</sup> International Fermi Symposium

Terrestrial Gamma-ray Flashes



# Gamma-ray Bursts

2000 Fermi GBM GRBs



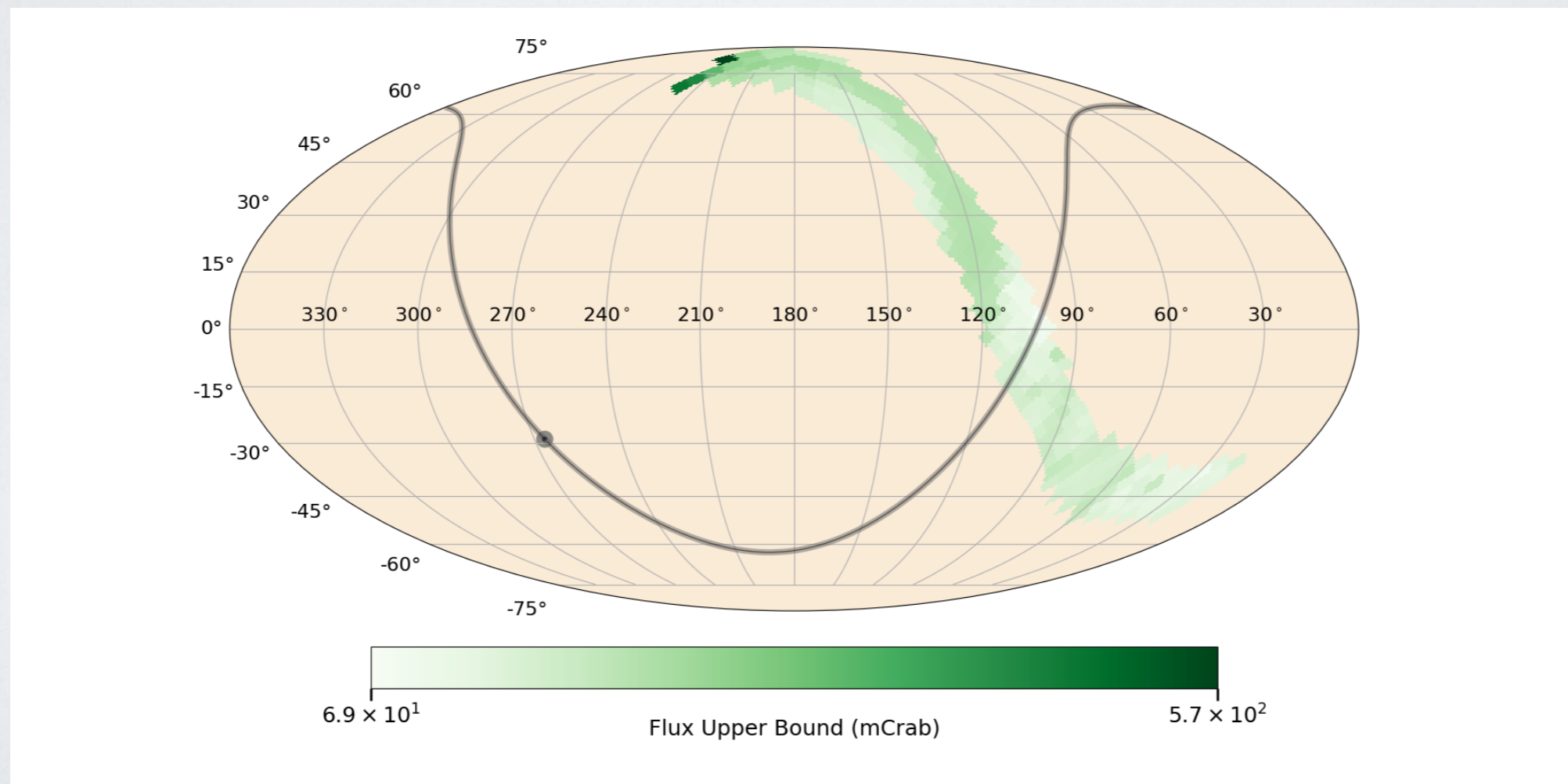
- Over 2000 GRBs have been detected since launching in 2008.
  - 200 long GRBs / year -> massive star collapse.
  - 40 short GRBs / year -> compact merger event.
  - 13% seen by Swift.
  - 52% within *Fermi* LAT FOV, 6% detected.

# Monitoring by Earth Occultation technique

[https://gammaray.nsstc.nasa.gov/gbm/science/earth\\_occ.html](https://gammaray.nsstc.nasa.gov/gbm/science/earth_occ.html)

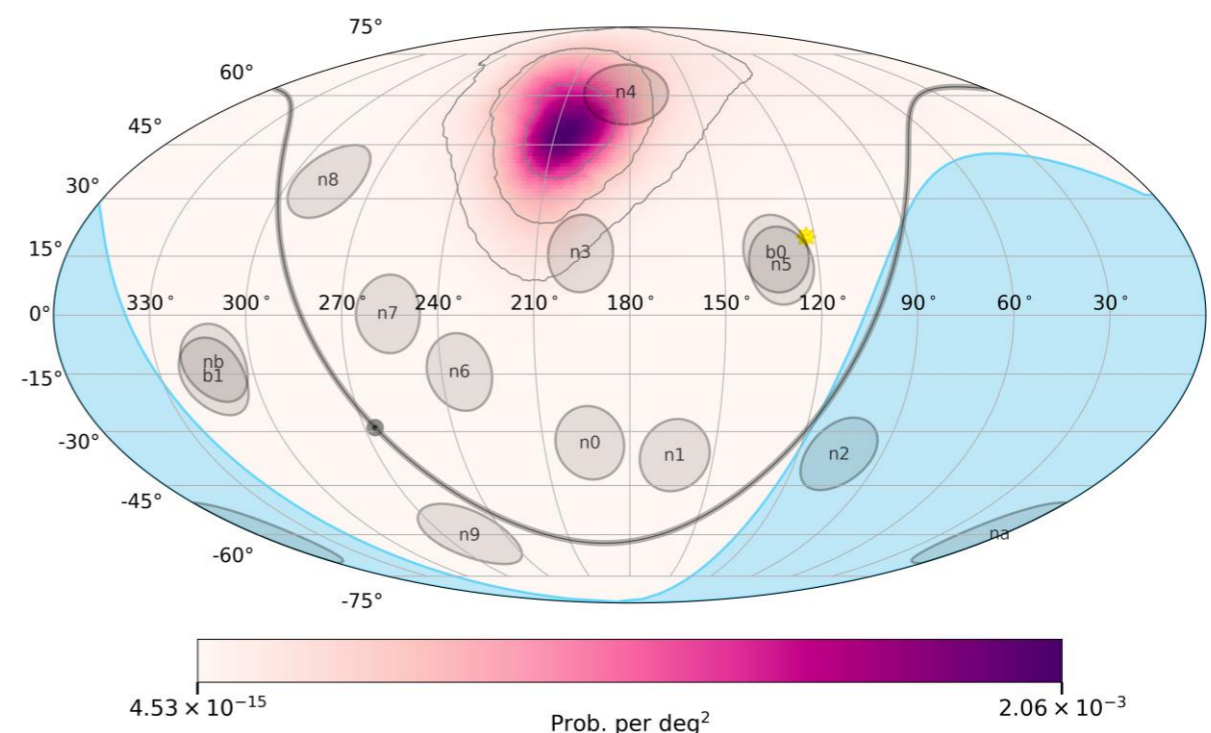
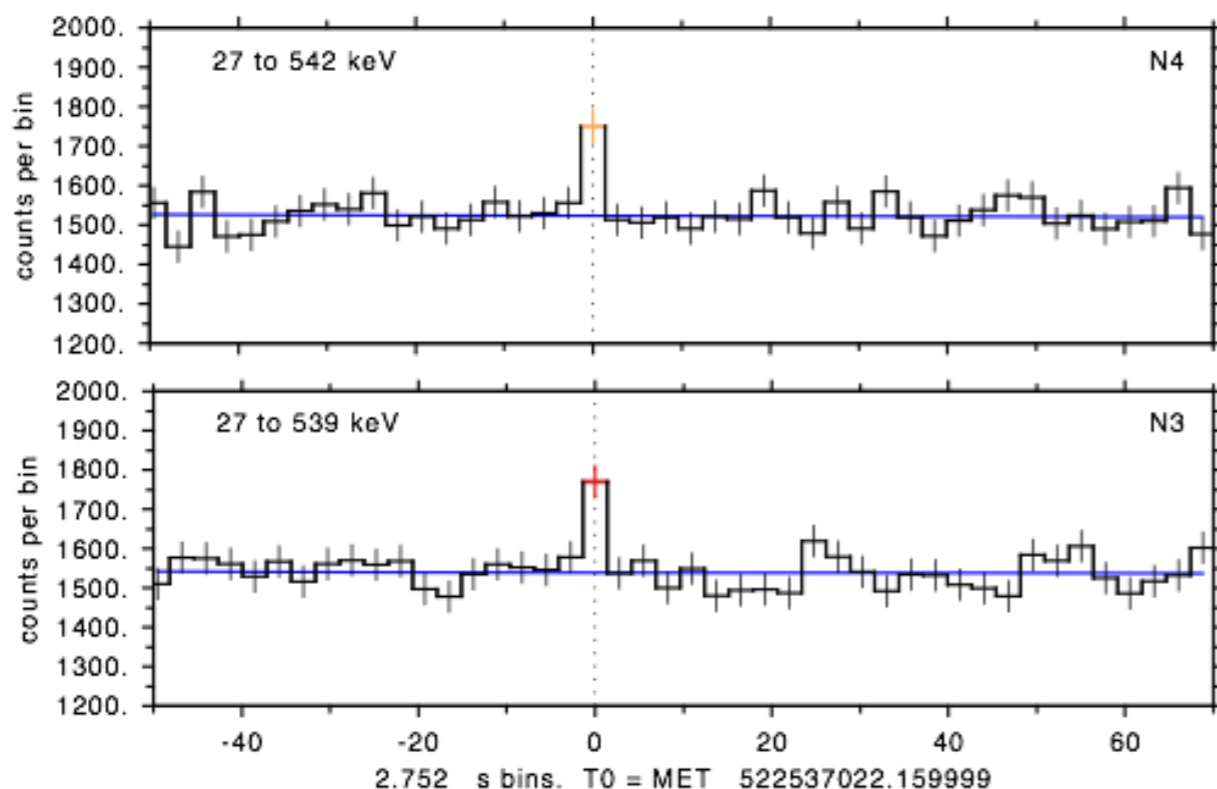
- 200+ sources are monitored from X-ray binaries to Active Galactic Nuclei.
  - 102 detections, 9 at  $>100$  keV.
- Earth occultation technique can be used to search for longer term emission from GW candidates

## GW 170104 upper limits map (+/- 1 day)



# Offline GRB search

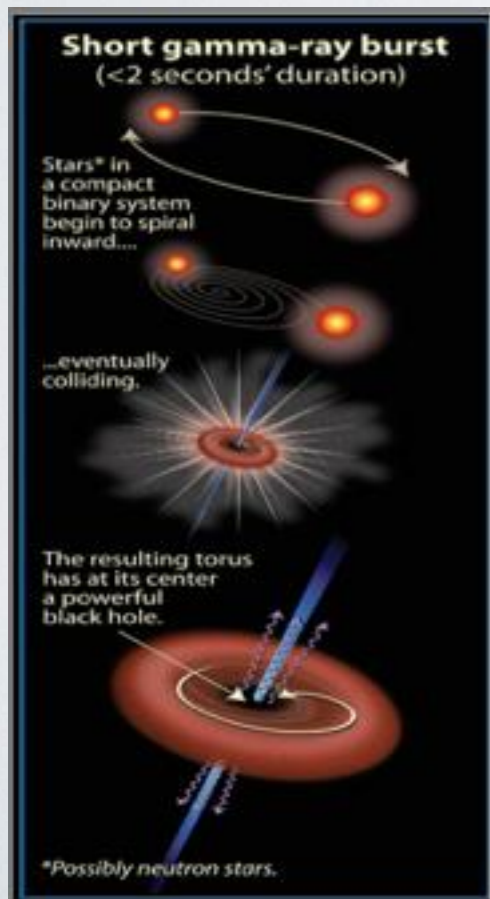
- **Untargeted** search in the Continuous Time Tagged Events (CTTE) data.
  - 18 timescales: 64ms to 32 s
  - Four energy ranges
- GCN now available, more info at [https://gcn.gsfc.nasa.gov/fermi\\_gbm\\_subthreshold.html](https://gcn.gsfc.nasa.gov/fermi_gbm_subthreshold.html)
  - Currently short timescale pipeline is released, long (2.8+s) pipeline is in progress.
  - Expected rate is ~70/month (during periods of Cyg X-1 activity, it may increase by 4x).
  - Current time delays range from 0.5 to 6 hours due to ground processing and data downlink.
  - Location uncertainties are in the range of 10 to 40 deg (68% containment radius).
- List of candidates from older data (2013 and on) are available. [http://gamma-ray.nsstc.nasa.gov/gbm/science/sarb\\_search.html](http://gamma-ray.nsstc.nasa.gov/gbm/science/sarb_search.html)



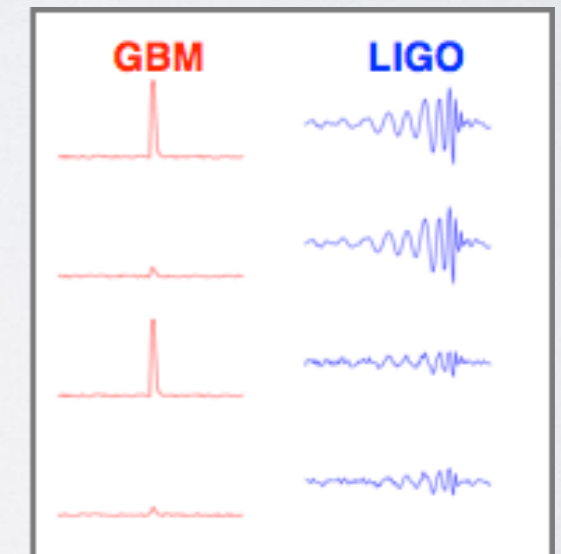
# Offline GRB search



- **Targeted** search in the Continuous Time Tagged Events (CTTE) data. (Blackburn et al. 2015, Goldstein et al. arXiv:1612:02395)
  - Looks for coherent signals in all detectors given an input time and optional skymap.
  - Calculate likelihood ratio of source and background.
  - Search +/- 30 seconds of input event time.
  - Sliding timescales from 0.256s to 8s (capable down to 0.064s) with a factor of 4 phase shift.
  - 3 source spectral templates using Band function: soft, normal, and hard.

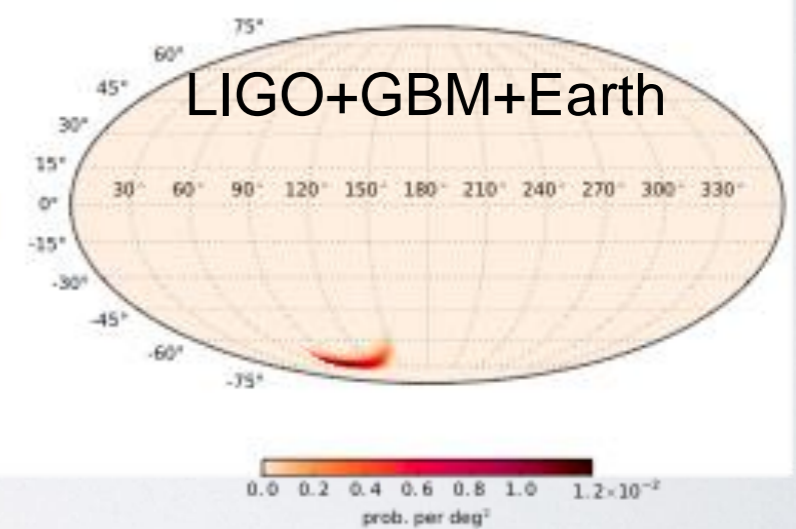
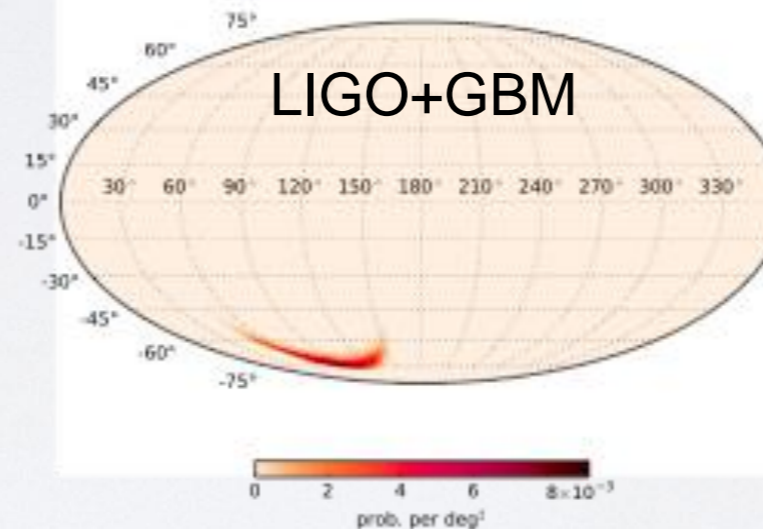
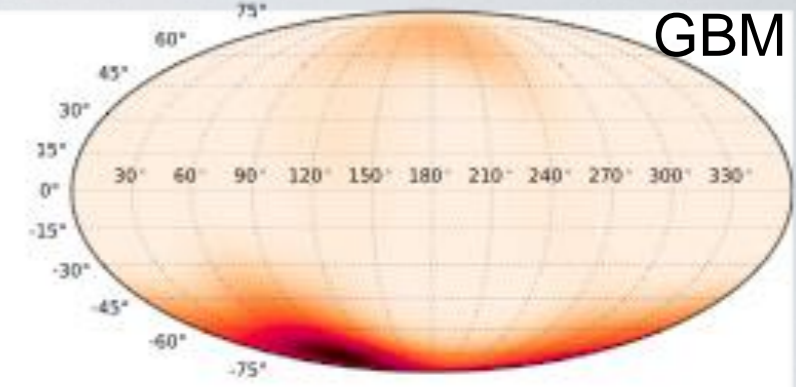
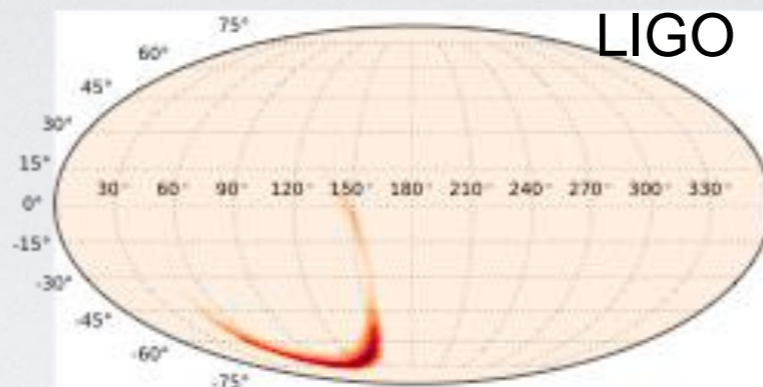
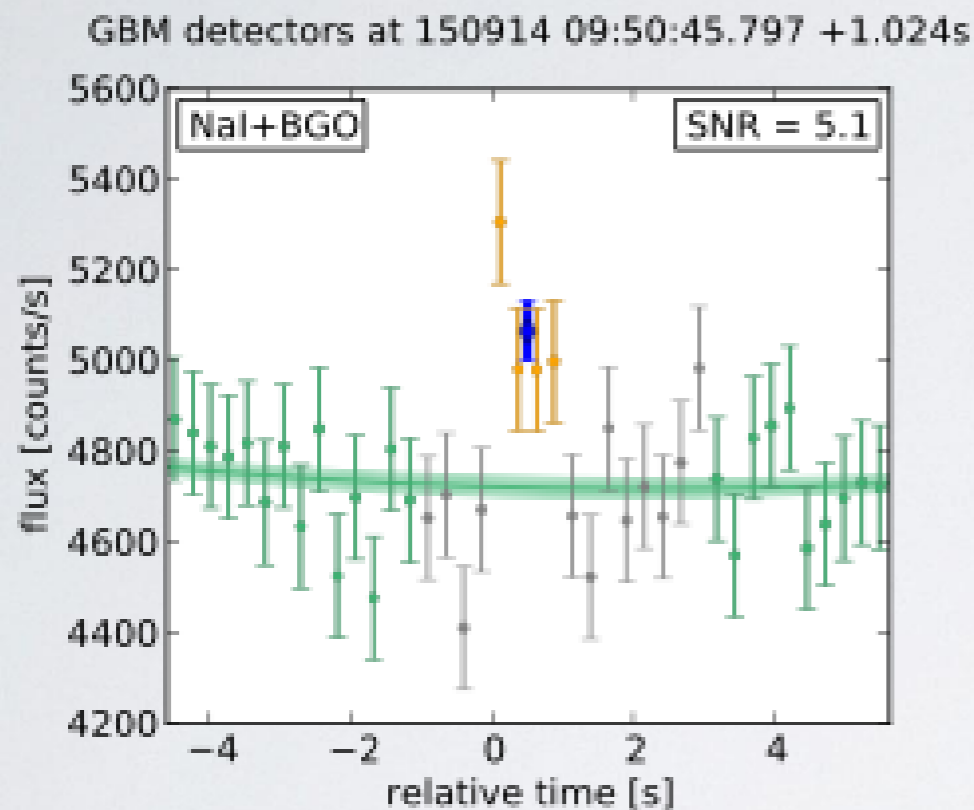


<b>Ideal Scenario</b>	Bright GBM	Bright LIGO
<b>GW150914 Scenario</b>	Sub-threshold GBM	Bright LIGO
<b>Typical more distant short GRB</b>	Bright GBM	Sub-threshold LIGO
<b>Both Sources Faint</b>	Sub-threshold GBM	Sub-threshold LIGO



# Follow-up to Gravitational Wave Event GW150914

Connaughton et al. ApJL 2016

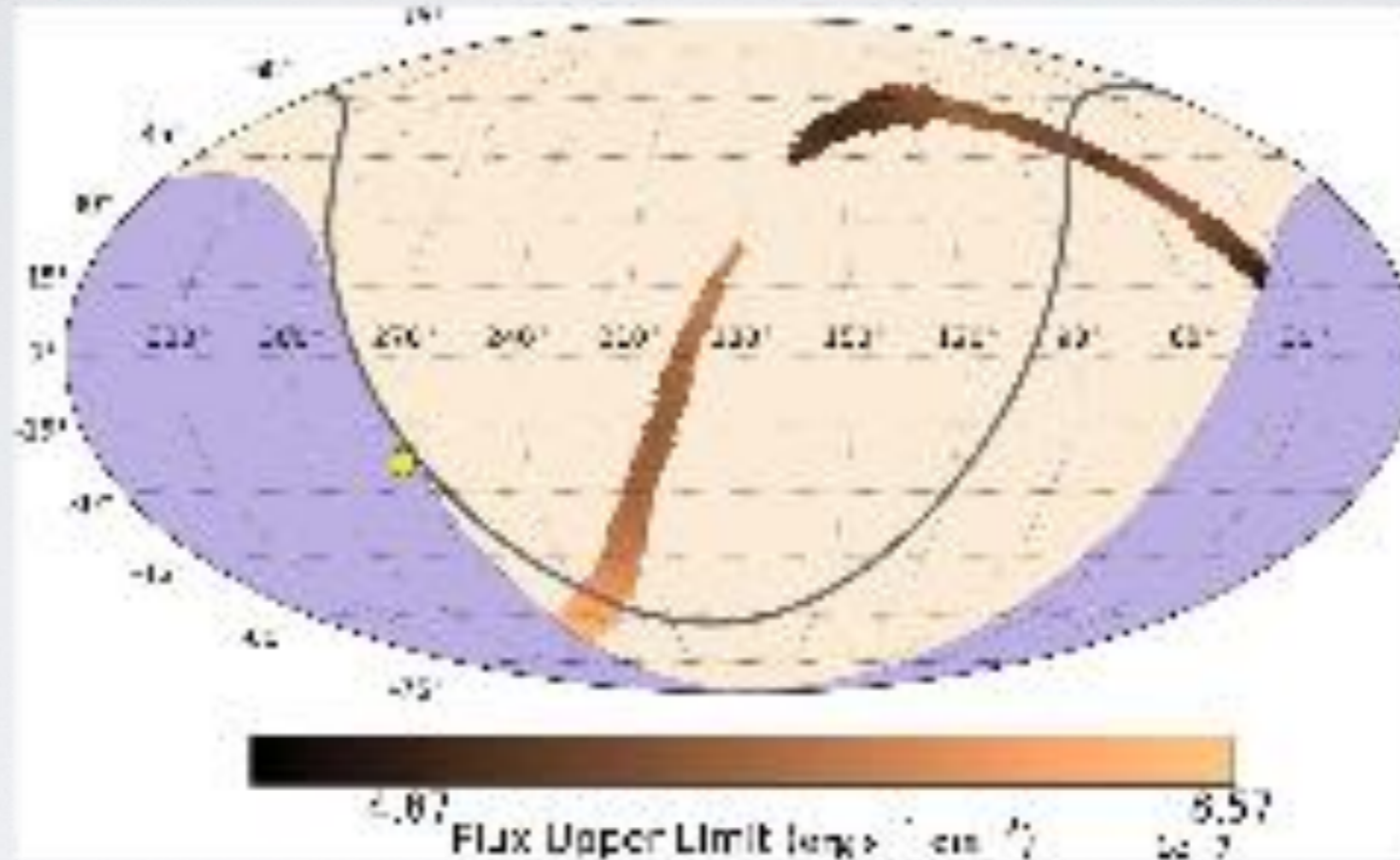


601 sq deg → 199 sq deg

- Untriggered sub-threshold signal 0.4s after LIGO trigger.
- Consistent with a low-fluence short GRB coming from behind Fermi.
- Poorly localized but consistent with LIGO localization.
- 0.2% post-trials probability in statistical fluctuation.

# Follow-up to Gravitational Wave Events

Racusin et al. ApJ 2017



- $3\sigma$  flux upper limit to GW151226 at 10—1000 keV, calculated from count rates  $\pm 30$ s of the GW trigger time.
  - Spectrum assumed to be cutoff power-law with  $E_{\text{peak}} = 566$  keV and photon index of 0.42
- Based on provided location probability map, we can calculate upper bounds on impulsive gamma-ray emission.

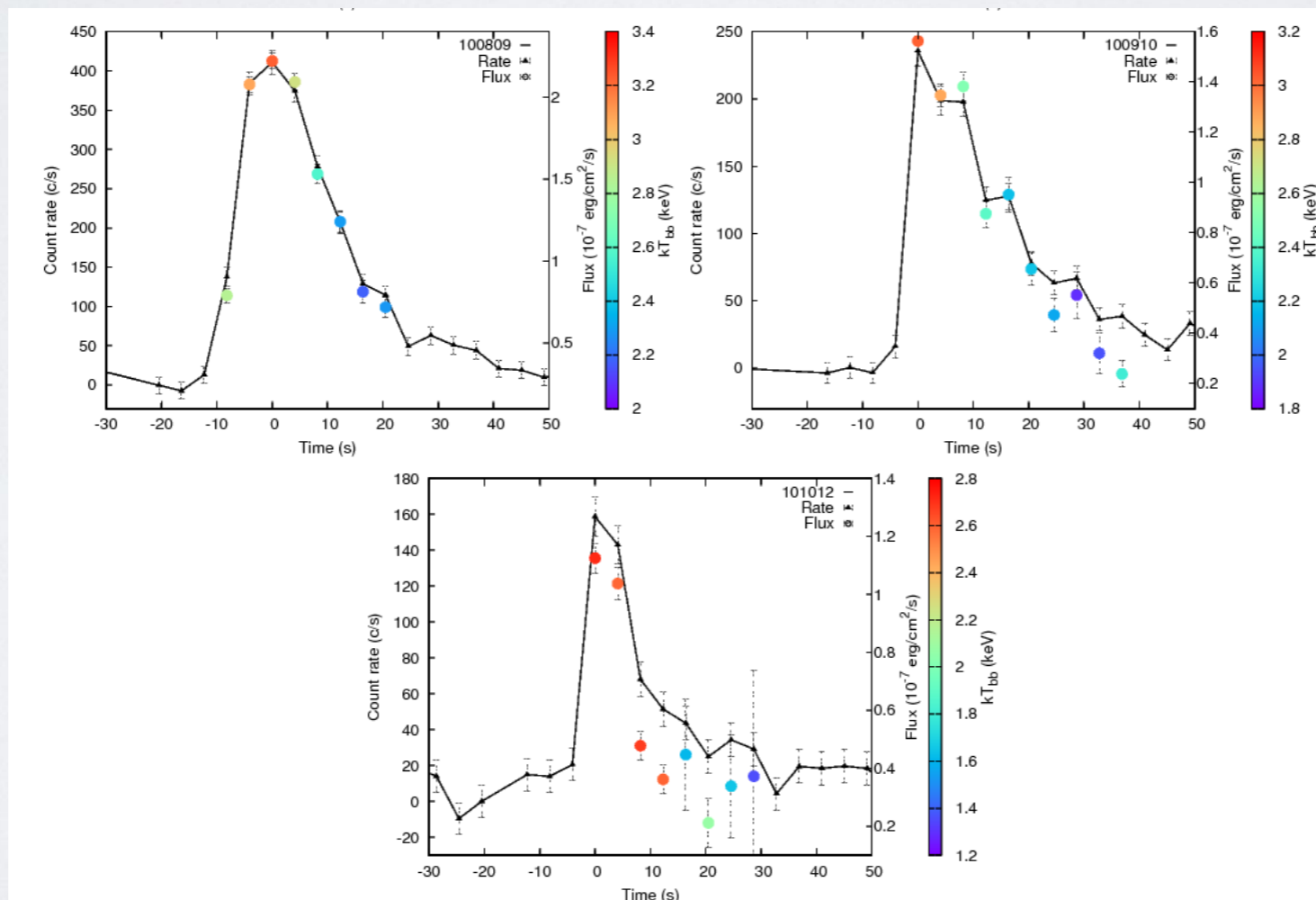
# Follow-up to IceCube neutrino Events

- Utilizes all search methods:
  - On-board triggers.
  - Targeted search using event time.
  - Untargeted search within the hour.
  - Earth occultation technique.
- Good follow-up observation for IceCube-161103, upper limit published in GCN 20127.
- Other followup with limited GBM coverage: IceCube-170321A (GCN 20932).
- Also can use these techniques to search for counterparts to Fast Radio Bursts

# X-ray Bursts

- 1084 Type I X-ray bursts detected between 2010 and 2013 (Jenke et al. 2013)
- GBM is particularly sensitive to photospheric expansion bursts
- Average of 1.4 bursts from all bursters <10 kpc
- Average blackbody temperature is  $3.2 \pm 0.3$  keV
- <https://gammaray.nsstc.nasa.gov/gbm/science/xrb.html>

## 4U 0614+09

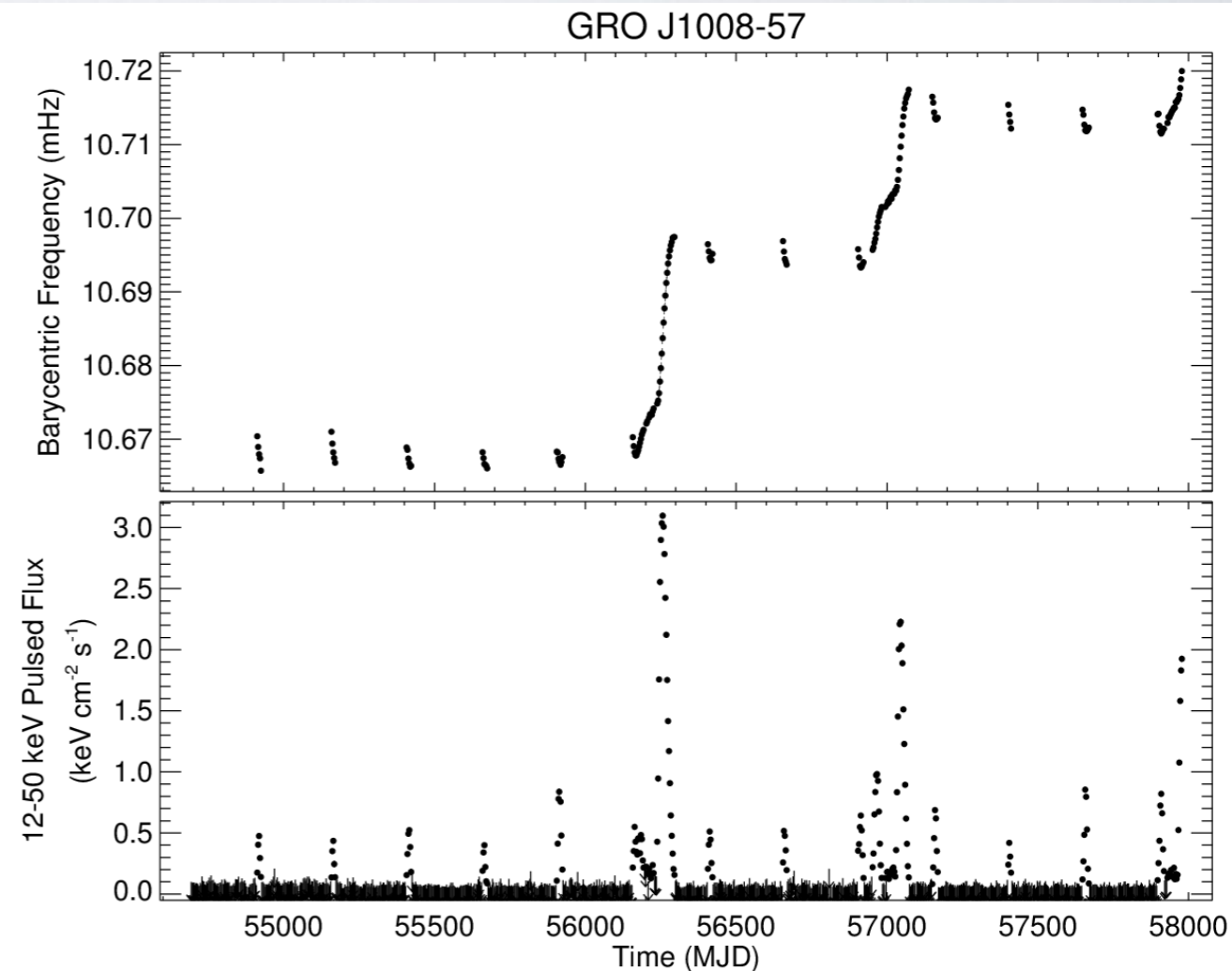
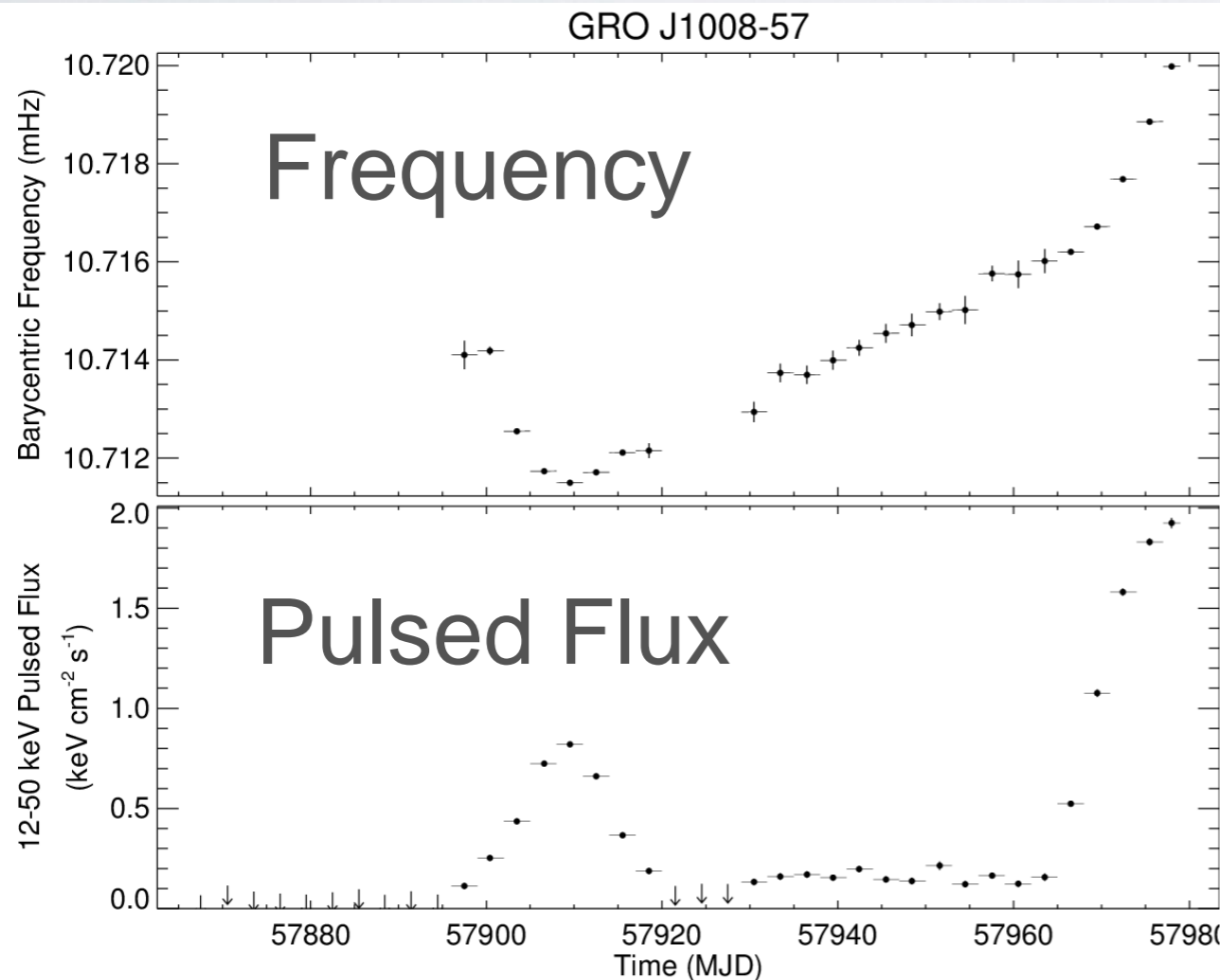


Linares et al. 2012

# Accretion Powered Pulsar Monitoring

- Daily blind searches for new pulsars and new outbursts
- Epoch folded searches for 39 systems (36 detected to date)
- <https://gammaray.nsstc.nasa.gov/gbm/science/pulsars.html>

## GRO J1008-57



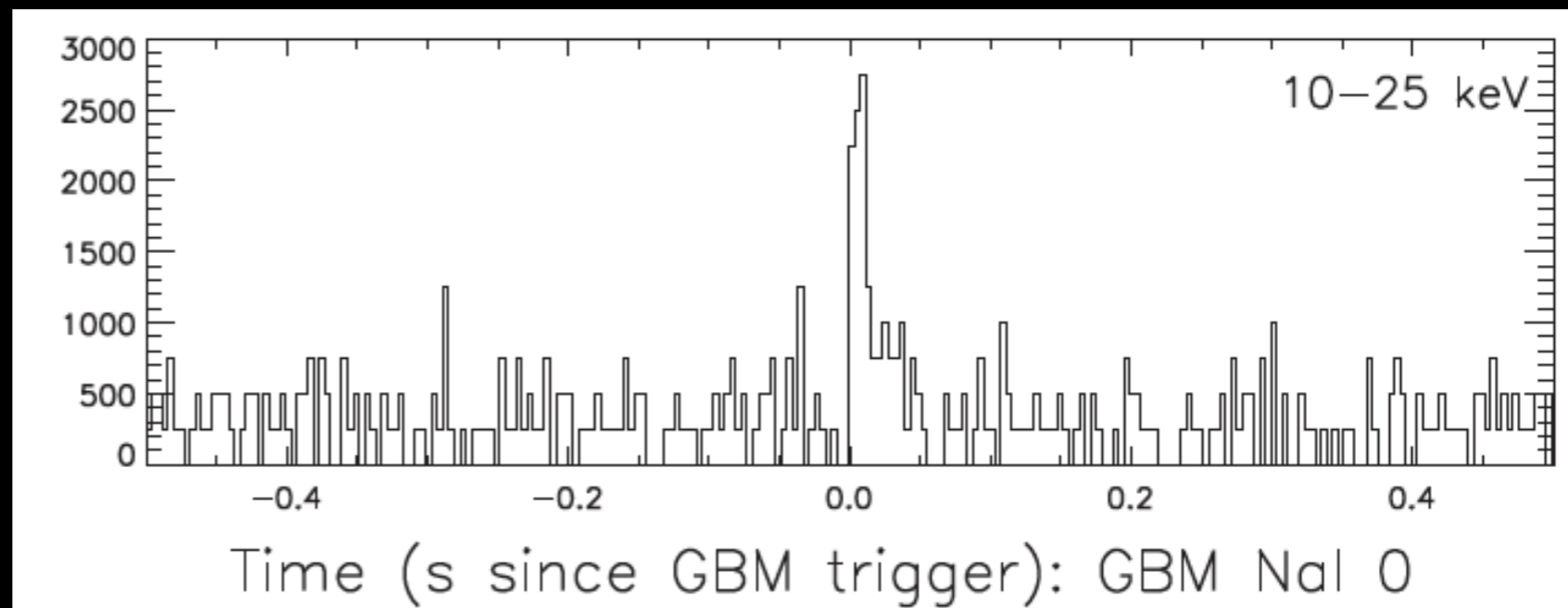
# Magnetars and High-B pulsars

High-B pulsar **PSR J1119-6127**

GBM detected the most bursts from the source, a total of 10.

Burst properties similar to low-bursting typical magnetars

Glitch reported at the time of the 1<sup>st</sup> GBM trigger



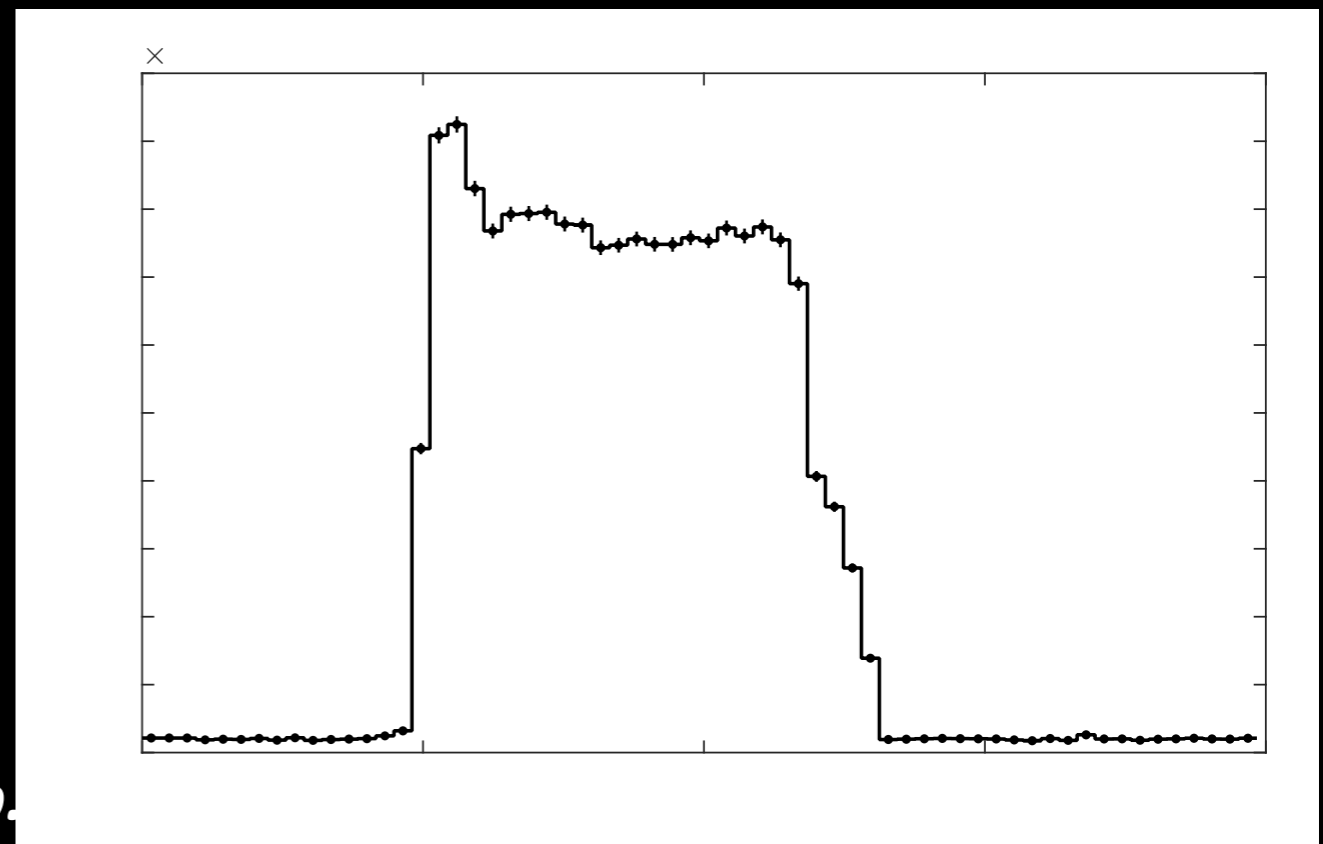
*Gogus et al. 2016, Archibald et al. 2016*

Magnetar **SGR J1935+2154**

3 outbursts detected with GBM: 2015 February  
2016 May, and June with >100 bursts total

Some 2016 June bursts were longer than  
typical magnetar bursts with flat-top shape

Energy in bursts in 2016 (May + June) exceeds  
total persistent emission energy in outburst



*Younes et al. 2017, Lin et al. 2017 in prep.*

# Other magnetar outbursts

4U 0142+61	2015 Feb	>10 (Gogus et al. 2016)
1E 1841—045	Scattered	~10
SGR 1806-20	Scattered	5

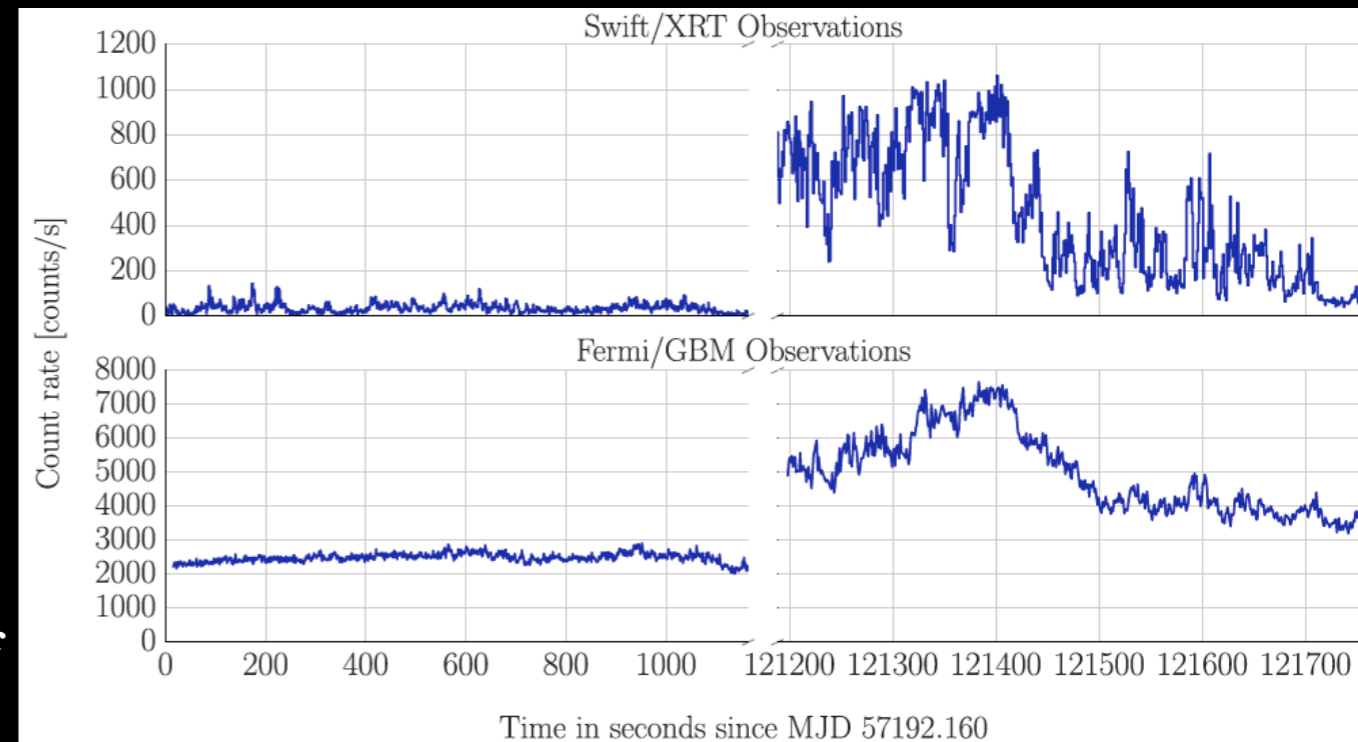
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## QPO detections in **V404 Cyg**

QPO analysis of V404 Cyg light curves during its 2015 outburst.

Data from 5 different telescopes with majority of data coming from GBM.

Discovery of a very low frequency (18 mHz), QPO in a simultaneous GBM/XRT detection of the source.



*Huppenkothen et al. 2017*

# Summary

- GBM continues to be prolific in detecting GRBs and monitoring pulsars and Galactic transients.
- GCN notice of subthreshold GRB candidate events are now available.
- Continued development of offline data searches for joint detection of astrophysical transients with neutrinos and gravitational waves.